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Middle Miocene-Pliocene freshwater gastropods of the Churia Group, west-central Nepal

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Abstract. **In the Churia (Siwalik) Group of west-central Nepal fossil freshwater molluscs occur in relative abundance. No systematic study of these fossils has been done. Therefore, in this paper freshwater gastropods belonging to nine genera, including two new species, are described: *Bellamya celsispiralis*, sp. nov., *Bellamya* sp. A, *Bellamya* sp. B, *Angulyagra* sp., *Pila* sp., *Bithynia* sp., *Melanoides* sp., *Brotia palaeocostula*, sp. nov., *Brotia* sp. A, *Brotia* sp. B, *Brotia* sp. C, *Lymnaea* sp., *Indoplanorbis* sp., and *Gyraulus* sp. The genus *Angulyagra* is recorded for the first time from the Siwaliks.**

Key words: Churia (Siwalik) Group, freshwater gastropods, Middle Miocene-Pliocene, Nepal.

Introduction

The Churia Group in west-central Nepal is of Middle Miocene to Plio-Pleistocene age and composed of molasse sediments, 5-6 km thick. It is considered equivalent to the Siwalik Group of India and Pakistan, which is well studied at the type locality of Northern Pakistan (Pilgrim, 1910; Johnson *et al.*, 1982, 1985). Recently, many geological studies were carried out in different areas of the Siwaliks of Nepal and these have resulted in the establishment of an independent lithostratigraphy (Glennie and Ziegler, 1964; Tokuoka *et al.*, 1986, 1988, 1990; Corvinus, 1994; Dhital *et al.*, 1995) for each area. These molasse sediments, showing a coarsening-upward sequence, are considered syntectonic deposits associated with the upheaval of the Himalayas. Various studies to decipher the geological history of the rising Himalayas and effects on the climate, environment, and distribution of the flora and fauna through time have been carried out in the Churia Group of Nepal (Awasthi and Prasad, 1990; Hisatomi and Tanaka, 1994; Quade *et al.*, 1995; Takayasu *et al.*, 1995). In the Churia Group of west-central Nepal, freshwater molluscs are locally abundant. The present study is an initial step in examining their relationship to changing environments through the time of uplift of the Himalayas. With this and one earlier paper (Takayasu *et al.*, 1995) we hope to record the number of genera of fossil molluscs from the Nepal Siwaliks, which could be of help for further comparison with similar faunas from other parts of the Siwaliks. In addition, the paleontological data can be of interpretive value to the reconstruction of paleoenvironments, paleobiogeographic distribution, and stratigraphic correlation.

The fossil specimens were collected from localities reported by Tokuoka *et al.* (1986, 1988, 1990) and from those added by us in subsequent field work. Part of the systematic description of these fauna was carried out in our earlier paper (Takayasu *et al.*, 1995), which reported on nine taxa belonging to four genera of Bivalvia. In the present paper fourteen gastropod taxa, including two new species, belonging to nine genera are described.

Geological Setting

The fossil localities cover the valleys of the Arungkhola, Binaikhola and Tinaukhola rivers, about 250 km southwest of Kathmandu in west-central Nepal (Figure 1). The lithostratigraphy of the Arung-Binaikhola area was established by Tokuoka *et al.* (1986), and was extended westward up to the Tinaukhola area by Tokuoka *et al.* (1988, 1990) (Figure 2). Due to lack of isotopically dateable beds, the age of the group is controlled by paleomagnetic polarity chrons. Magnetic polarity stratigraphy measured by Tokuoka *et al.* (1986) is compared with the La Brecque *et al.* (1981). In this report the same measured polarity chrons are correlated with the timescale of Cande and Kent (1992, 1994) (Figure 3). The formational boundaries therefore differ slightly from the previous report (Takayasu *et al.*, 1995) (Figure 3). The formational boundary between the Arung Khola Formation and Binai Khola Formation became older by 0.8 Ma and between the Binai Khola Formation and Chitwan Formation become younger by 0.3 Ma.

The Churia Group is divided into the Arung Khola, Binai

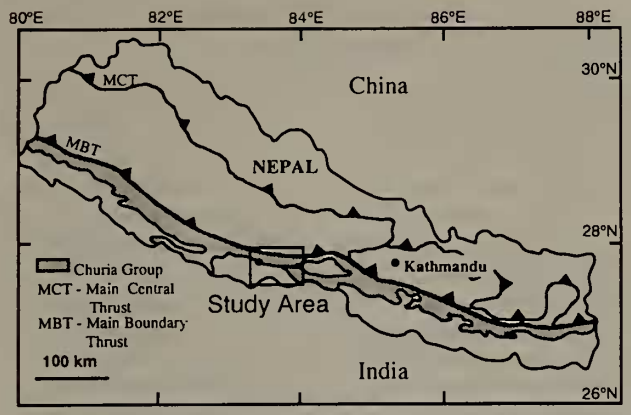


Figure 1. Index map of the study area.

Khola, Chitwan and Deorali Formations, in ascending order, and is divided into South and North Belts by the Central Churia Thrust (Figure 2). The group is separated from the northern older Midland Group by the Main Boundary Thrust (M.B.T.), and from the southern younger Gangetic Alluvium by the Frontal Churia Thrust (F.C.T.). The Arung Khola Formation (9.3–14 Ma) is composed mainly of alternating beds of variegated siltstone and sandstone with finer sediment dominating. It is divided into lower, middle and upper members. The sandstone beds become thicker toward the upper part. The Binai Khola Formation (2.7–9.3 Ma) is dominated by alternating beds of sandstone and siltstone, the sandstone beds being much thicker and the siltstone beds not variegated; it is further divided into lower, middle and upper members. The Chitwan Formation (1.3–2.7 Ma) is composed of clast-supported pebble to cobble conglomerates. The Deorali Formation (<1.3 Ma) is dominated by matrix-supported cobble to boulder conglomerates and alternating beds of coarse-grained sandstone.

The molluscan fossils are found from the upper member of the Arung Khola Formation, dated as about 10.5 Ma, to the upper part of the middle member of the Binai Khola Formation, about 3.5 Ma (Figure 3). The molluscan fossil occurrences are not continuous stratigraphically; they are wanting between 9 Ma to 8 Ma and 6 Ma to 5 Ma. Generally the fossil shells are better preserved in the younger localities than in the older ones. All of the gastropod taxa are aquatic prosobranchs and three are aquatic pulmonates (Table 1).

Systematic paleontology

All the specimens described here are deposited at the Toyohashi Museum of Natural History (TMNH), Toyohashi, 441-31 Japan.

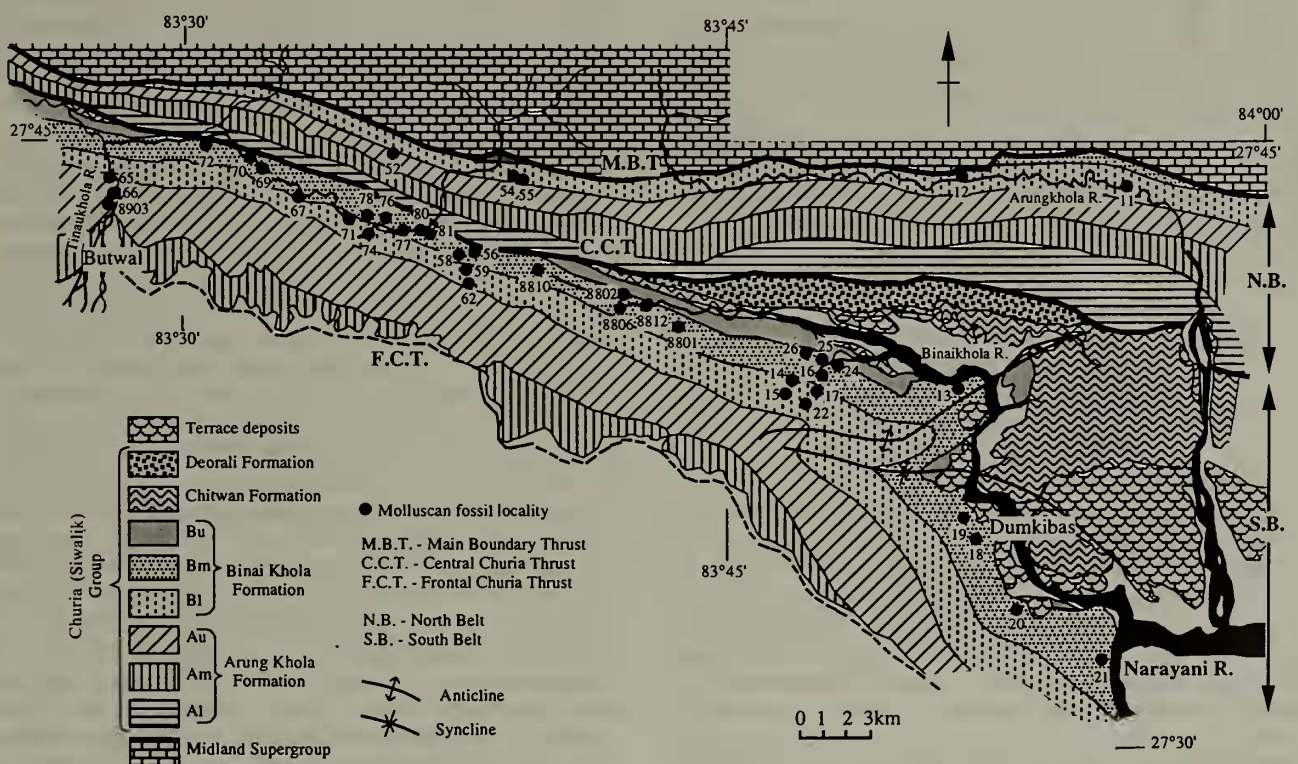


Figure 2. The generalized geologic map of the Arungkhola-Tinaukhola area, west-central Nepal after Tokuoka *et al.* (1986, 1988, 1992) with fossil localities. Locality numbers have prefix "F-".

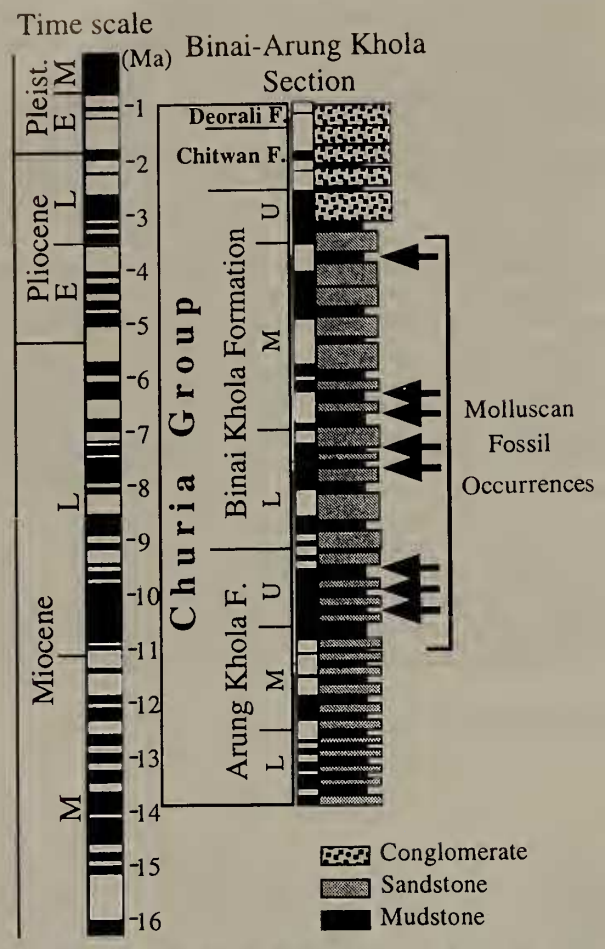


Figure 3. Generalized stratigraphic column of the Churia (Siwalik) Group with polarity chron of Tokuoka et *al.* (1986) correlated with the magnetic stratigraphy of Cande and Kent (1992) and the occurrences of the molluscan fossils.

Table 1. List of the Gastropoda taxa from the Churia (Siwalik) Group, west-central Nepal.

Class Gastropoda	Genus *Brotia*
Subclass Prosobranchia	*Brotia palaeocostula*
Order Mesogastropoda	*Brotia* sp. A
Family Viviparidae	*Brotia* sp. B
Subfamily Bellamyinae	*Brotia* sp. C
Genus *Bellamya*	Subclass Pulmonata
Bellamya celsispiralis	Order Basommatophora
Bellamya sp. A	Family Lymnaeidae
Bellamya sp. B	Genus *Lymnaea*
Genus *Angulyagra*	*Lymnaea* sp.
Angulyagra sp.	Family Planorbidae
Family Ampullariidae	Subfamily Bulininae
Genus *Pila*	Genus *Indoplanorbis*
Pila sp.	*Indoplanorbis* sp.
Family Bithyniidae	Subfamily Planorbinae
Genus *Bithynia*	Genus *Gyraulus*
Bithynia sp.	*Gyraulus* sp.
Family Thiaridae	
Genus *Melanoides*	
Melanoides sp.	

Class Gastropoda
Subclass Prosobranchia
Order Mesogastropoda Thiele, 1929
Family Viviparidae Gray, 1847
Subfamily Bellamyinae Rohrbach, 1937
Genus ***Bellamya*** Jousseaume, 1886

Type species.—*Paludina bellamyi* Jousseaume. Recent: Senegal, West Africa.

Distribution.—Africa, South, East and Southeast Asia.

Geologic range.—Jurassic to Recent.

Remarks.—The shell of the genus is turbiniform with ovately rounded aperture, pointed apex and rounded base. Whorls are rounded and almost smooth without traces of distinct spiral ridges or sculpture. Umbilicus narrow or closed.

This operculate gastropod from the Indian subcontinent was generally described under the generic name *Paludina* Lamarck and then later referred to by the senior name of *Viviparus* or *Vivipara* Lamarck. The genus *Idiopoma* established by Pilsbry (1901) with "*dissimilis*" as the type species was used as a subgenus of *Vivipara* by Preston (1915) but at present "*dissimilis*" is grouped in the genus *Bellamya* Jousseaume. According to Prashad (1928) the African species *B. unicolor* (Olivier) is very closely allied to the Indian species *V. dissimilis* (Müller). The name *Viviparus sensu lato* for the Asian and African species has been generally discarded following the anatomical study of Rohrbach (1937) which pointed out the differences from *Viviparus sensu stricto*. Yen (1943) also assigned *Viviparus* (s. l.) or the group called "*Vivipari dissimilis*" in *Bellamya*. Similarly, Subba Rao (1989) has grouped the Indian viviparids into *Bellamya* Jousseaume; *Cipangopaludina* Hannibal; *Angulyagra* Rao; and *Taia* Annandale. Common species of living viviparids in the Indian subcontinent are *Bellamya bengalensis* (Lamarck) and *B. dissimilis* (Müller), the second- and third-mentioned genera are distributed in Assam (Northeast India), Burma, and East Asia, and the last genus is considered to be endemic to Burma. Annandale and Seymour Sewell (1921) included all Indian forms with dark-banded shells into *V. bengalensis* (Lamarck) with one form *nepalensis* from "Nepal Valley". The present fossil specimens show close affinities with the recent genera *Bellamya* Jousseaume and *Angulyagra* Rao.

Hislop (1860) was the first to record fossil viviparids from the Indian subcontinent with materials from the Late Cretaceous Intertrappean Beds. He reported twelve species of *Paludina* Lamarck, but Annandale (1921b) found only *Paludina normalis* Hislop, to be a true viviparid, belonging to the group of *Vivipara dissimilis* (Müller). Fossil *V. bengalensis* was reported from the Pliocene Nerbuddah Gravel, India, by Annandale (1921b).

Bellamya celsispiralis sp. nov.

Figures 4-1—4

Materials.—TMNH02098, TMNH02099, TMNH02100, TMNH02101.

Diagnosis.—Shell elongated turbinate in shape, spire high, spire nearly equal to body whorl and whorls much rounded with impressed suture.

Description.—Shell medium in size for the genus, about 18 to 23 mm high, dextral, elongated turbinate in shape and moderately solid. Spire elevated, long, equal or slightly longer than the body whorl, apical angle about 50°, consisting of six whorls, gradually and regularly increasing in size. Apex not preserved. Whorls rounded and separated by impressed suture. Body whorl not greatly enlarged in size. Shell surface marked with coarse and fine slightly opisthoclined growth lines. Aperture (not completely preserved in the holotype but as observed in the paratypes) broadly ovate, small, thinly lipped, slightly angled on adapical side with continuous margin; inner lip thicker than the outer lip; umbilicus imperforate to narrowly perforate.

Type.—Holotype: Figures 4-1a, b, TMNH02098. Paratypes: Figures 4-2—4, TMNH02099, TMNH02100, TMNH02101.

Measurements (in mm).—

TMNH* coll. cat. no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02098 (Holotype)	21.8	13.3	12.7	7.8+	50°
02099 (Paratype-1)	19.2	14.3	—	—	50°
02100 (Paratype-2)	23.0	16.4	—	—	45°
02101 (Paratype-3)	18.4	15.7	10.0	—	50°

* Toyohashi Museum of Natural History

Etymology.—The name is given after its rather high spire.

Type Locality.—About 500 m west of Dumkibas along the Mahendra Highway (F-18 in Figure 2). Middle member of the Binai Khola Formation.

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Localities.—F-18, F-21.

Remarks.—The present fossil species has an elongated turbinate shape shell with smooth rounded whorls with a characteristically long spire. The recent and fossil species belonging to the genus *Bellamya* Jousseaume do not possess a spire longer than the height of the body whorl. The recent species of *Bellamya* common in the Indian subcontinent and Southeast Asia have spires shorter than the body whorl.

V. hasani Prashad which is considered to be from the Nerbuddah alluvial deposit (embedded in consolidated sandstone, which may have been derived from an older formation), India, is somewhat similar in shape and size, but has weak peripheral angulation and a spire shorter than the body whorl. *Paludina bugtica* Blanford, 1883, and *Vivipara atavia* Annandale, 1921b, from Oligo-Miocene beds of Gaj Stage, Bugti Hills, Baluchistan, differ from the present species in having less inflated whorl and a shorter spire. The present species differs from *Vivipara gregoriana* Annandale, 1924, and *V. dubiosa* Annandale, 1924, from [illegible] Pliocene Dawna Hills of Burma, in possessing more round[illegible] whorls with a well impressed suture.

Bellamya sp. indet. **A**

Figures 4-5—8

Materials.—TMNH02158, TMNH02159, TMNH02160, TMNH02161.

Description.—The shell is small in size for the genus, about 12 to 15 mm in height, but, owing to deformation, the original size cannot be accurately determined. The shell is dextral, subconically turbinate and thin; spire short, less than half the shell height, apical angle about 75°, consisting of five to six whorls with rapidly increasing whorl diameter. Earlier whorls very small, slightly shouldered below suture. Later whorls almost flat or slightly rounded with a moderately strong angulation below the suture. Suture weakly impressed. Body whorl greatly enlarged. Shell surface smooth, glossy with fine growth lines, original shell probably thicker. Aperture poorly preserved.

Measurements (in mm).—

TMNH coll. cat. no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02158	12+	12	6+	—	70°
02159	9+	10	4+	—	75°
02160	12+	11	6+	—	—
02161	11+	12—	7+	—	—

Stratigraphic range.—Upper member of the Arung Khola Formation to lower member of the Binai Khola Formation.

Fossil Localities.—F-65, F-11, F-12 (Figure 2).

Remarks.—The present species is placed under the genus *Bellamya* based on its shell morphology with its smooth rounded whorls, turbinate shape and lack of surface sculpture. From its small size and a little rounded whorl with weakly developed angulation just below the suture, it is most similar to *Bellamya dissimilis* (Müller). Because of the lack of well preserved specimens, specific identification is deferred.

Bellamya sp. indet. B

Figures 4-9—12

Materials.—TMNH02102, TMNH02103, TMNH02104, TMNH02105.

Description.—Shell small in size for the genus, commonly ranging from 10 to 15 mm in height, dextral, turbinate and somewhat thick. Spire slightly elevated, short, less than half the height and consisting of rounded whorls. Apical angle about 70°. Apex small. Whorl diameter rapidly increasing. Body whorl much larger, inflated, with smooth and convex periphery and basally rounded. Suture between whorls impressed. Surface of the shell very smooth and glossy, marked with very fine growth lines. Aperture oval with a slight angulation on adapical side. Aperture margin continuous, of uniform thickness; inner lip with narrow parietal

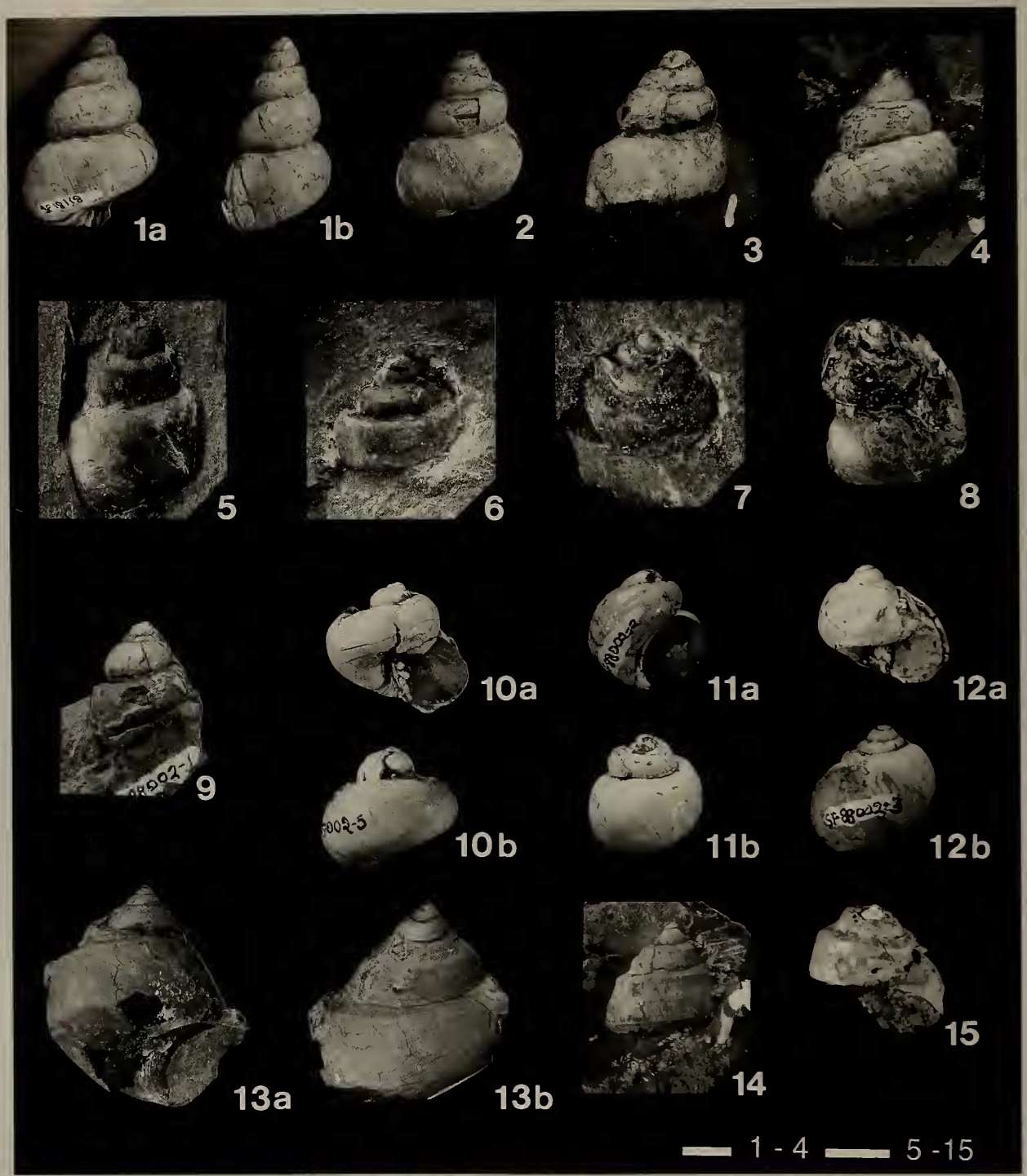


Figure 4. **1–4.** *Bellamya celsispiralis* sp. nov., 1 : holotype, TMNH 02098, 1a : adapertural view, 1b : side view, 2 : paratype 1, TMNH 02099, 3 : paratype 2, TMNH 02100, 4 : paratype 3, TMNH 02101. **5–8.** *Bellamya* sp. indet. A, 5 : TMNH 02158, 6 : TMNH 02159, 7 : TMNH 02160, 8 : TMNH 02161. **9–12.** *Bellamya* sp. indet. B, 9 : TMNH 02102, 10 : TMNH 02103, 11 : TMNH 02104, 12 : TMNH 02105. **13–15.** *Angulyagra* sp. indet., 13 : TMNH 02110, 14 : TMNH 02106, 15 : TMNH 02109. All scale bars : 5 mm.

callus. Umbilicus imperforate.

Measurements (*in mm*).—

TMNH coll. cat no.	Height	Width	Height of aperture	Height of body whorl	Apical angle
02102	10.6	9.0	—	7.5	70°
02103	11.0+	11.0	7.5+	10.0+	70°
02104	10.0+	9.4	7.8+	8.5+	70°
02105	10.0+	9.0+	—	8.0+	70°

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Locality.—F-88002.

Remarks.—At present the specimens are collected from only one locality (F-88002) and are few in number. *Vivipara atavia* Annandale (1921b) from the Oligo-Miocene Bugti Hills, Baluchistan, resembles the present species in having a short spire and impressed suture but the latter is smaller in size, with more rounded whorls. The Recent species *Bellamya micron* described by Annandale (1921a) from Manipur, Northeast India, is similar in shape and size to the present species, but the former has a blunt peripheral angle. Until more specimens from other localities can be found a species level determination is deferred.

Genus ***Angulyagra*** Rao, 1931

Type species.—*Paludina oxytropis* Benson. Recent: Manipur Valley, Northeast India.

Distribution.—Assam, Burma and China.

Geologic Range.—Oligocene to Recent.

Remarks.—The shell of the genus is medium in size, thin, conical in shape with spiral ridges, peripheral keel well developed and base flattened.

The genus was initially described as *Dactylochlamys* by Rao (1925). However, as the name was preoccupied a new generic name *Angulyagra* was proposed in 1931. The present species shows close affinities to this Southeast Asian genus *Angulyagra* in shell shape and sculpture. Recent species of this genus *A. oxytropis* (Benson) and *A. microchactophora* (Annandale) are reported from Manipur, Assam by Annandale (1921a). Yen (1943) reported the following species from China: *Angulyagra costata* (Quoy and Gaimard), *A. thersites* (Reeve), *A. oxytropoides* (Heude), *A. polyzonata* (Frauenfeld), *A. quangdungensis* (Kobelt), *A. annulata* (Yen).

Angulyagra sp. indet.

Figures 4-13—15

Materials.—TMNH02106, TMNH02107, TMNH02108, TMNH02109, TMNH02110.

Description.—Shell medium in size, dextral, conically turbinate in shape and thin. Spire moderately elevated, less than half of the shell height with five whorls. Earlier whorls rounded to weakly shouldered and latter ones strongly shouldered just below the suture. Apical angle about 70°. Initial whorls very small. Body whorl large, comprising of two thirds of the shell height, sides [illegible] and obliquely flattened and obtusely angled at the periphery. Base of the body whorl only slightly convex. Suture [illegible] abutting whorls. Shell surface with fine growth lines and two or three lines of the spiral sculpture. Aperture only partly preserved in some specimens, rounded oval with weakly reflected lip. Umbilicus imperforate to narrowly perforate.

Measurements (*in mm*).—

TMNH coll. cat. no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02106	10.0+	9.0	7.0+	—	68°
02107	20.0+	15.6+	10.7+	—	—
02108	15.0+	14.0+	10.0+	—	70°
02109	15.0+	15.0	—	—	—
02110	18.0+	16.0+	13.0+	7.0+	70°

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Locality.—F-13.

Remarks.—The specimens belonging to this genus are collected from only one locality, F-13. Most are incompletely preserved. The fossil shell is characterized by a thin and subconical shell. The occurrence of the genus *Angulyagra* in a fossil state so far west from its Recent distribution indicates that its past distribution may have been much wider. The surface spiral sculpture of the fossil species is weaker than in the Recent taxa. However, at present well preserved samples with a complete aperture are not available, preventing species level identification.

Family Ampullariidae Gray, 1847
Genus ***Pila*** Röding, 1798

Type species.—*Helix ampullacea* Linné, 1758. Recent: Asia.

Distribution.—Asia and Africa.

Geologic range.—Lower Eocene to Recent.

Remarks.—The genus is characterized by a shell with an inflated body whorl with large aperture and a short spire. The operculum is thick with an inner calcareous layer and nacreous columnar side. Recent species of this genus are widely distributed in the tropical regions of Africa and Asia.

Pila sp. indet.

Figures 5-1—3

Materials.—TMNH02111, TMNH02112, TMNH02113

Description.—Shell medium in size for the genus, dextral, reversely conic in shape and thin. Spire short, obtuse, consisting of five whorls. Body whorl very large, inflated below the weakly convex periphery. Shell surface marked by fine growth lines. Aperture also deformed but probably elongate pyriform as inferred from the shape of the operculum. Umbilicus narrowly perforated. Operculum thick, calcareous, light brown in colour and pyriform in shape. The upper margin narrowly rounded and somewhat elongate, lower margin regularly rounded. Outer surface with small

subcentral nucleus situated toward the inner margin, surrounded by concentric growth lines. Rim of the operculum slightly thickened. Inner surface with large muscle scar.

Measurements (in mm).—

TMNH coll. cat. no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02111	30.0+	36.0+	–	–	–
02112	24.4+	25.5+	24.4	21.7+	–
02113 (operculum)	21.6+*	15.7			

* Length

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Locality.—F-13 (Figure 2).

Remarks.—Few poorly preserved shells from locality F-13, with numerous fragmented shells. In all specimens the spire is depressed to the body whorl level due to deformation. Opercula are more numerous and better preserved than the shells. *Pachylabra (=Pila) prisca* Prashad, is the only fossil species of this genus reported from the Siwaliks. It is described by Prashad (1925) based on opercula collected from the Lower Siwalik (Chinji) series of Kashmir which are similar in size to the operculum of the present fossil specimen. However the latter is more elongate and thinner. As compared with the operculum of *Pila globosa* (Swainson), a Recent widely distributed species of the Indian subcontinent, the fossil one is narrower and elongated. Within the Recent species of the subcontinent, *P. virens* (Lamarck) has the most similar operculum to that of the present species. As most specimens are poorly preserved, the characters needed for species identification are insufficient.

Family Bithyniidae Walker, 1927
Genus ***Bithynia*** Leach, 1818

Type species.—*Helix tentaculata* Linnė. Recent: Europe.

Distribution.—Europe and Asia.

Geologic range.—Miocene to Recent.

Remarks.—This genus is characterized by a small, ovate-conoidal shell with very delicate spiral lines; without a varix parallel to the peristome; calcareous operculum with a paucispiral nucleus.

Bithynia sp. indet.

Figures 5-4—10

Materials.—TMNH02114, TMNH02116, TMNH02117, TMNH02118, TMNH02121, TMNH02122, TMNH02123.

Description.—Shell small in size, ranging from 2 to 5 mm, dextral, ovate-conoidal in shape, somewhat thick. Composed of four regularly increasing whorls, rounded and convex. Body whorl larger than spire, periphery and base rounded. Suture distinct but shallow. Shell surface corneous, somewhat glossy and sculptured with delicate lines of growth only. Aperture partially observed, ovate in outline, lip slightly reflected. Umbilicus closed. Operculum calcareous, ovoidal in shape, white colour, concentric with large subcentral nucleus, internal surface convex with a flattened border on the outer margin with raised rim.

Measurements (in mm).—

TMNH coll. cat. no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02114	2.3+	1.8	1.2+	–	48°
02115	3.2+	3.0+	2.0+	–	–
02116	5.8+	3.5	3.6+	–	48°
02117	3.3+	2.3+	2.0+	–	–
02118	–	2.2	2.2+	1.5+	–
02119	–	2.0	2.2+	–	–
02120	–	2.0+	2.2+	1.5+	–
02121	2.3	1.8	1.2	–	50°
02122 (operculum)	1.8*	1.2	–	–	–
02123 (operculum)	1.9*	1.3	–	–	–

* Length

Stratigraphic range.—Upper member of the Arung Khola Formation to middle member of the Binai Khola Formation.

Fossil Localities.—F13 and F21 (shell and operculum); F65, F18, F19, F17 (only opercula).

Remarks.—According to Subba Rao (1989) and Annandale (1920) the subfamily Bithyniinae of the Indian subcontinent can be divided on the basis of shell characters into five genera: *Bithynia* Leach, *Sataria* Annandale, *Gabbia* Tryon, *Dignostoma* Annandale and *Hydrobioides* Nevill. Based on the shell morphology and its calcareous operculum with concentric growth lines and subcentral nucleus, the present specimens are identified as a species of *Bithynia* Leach. Shells of *Bithynia* sp. are found along with opercula at two localities only (F-13, F-21), although white calcareous opercula are found at most localities. The opercula are not found attached to the shell and they are of a different shape and size, probably belonging to two or more species. Most of the tiny shells are fragile and difficult to separate from the sediment containing them, so preventing specific identification.

Family Thiaridae Gray, 1847
Genus ***Melanoides*** Olivier

Type species.—*Melanoides fasciolata* Olivier=*Nerita tuberculata* Müller. Recent: India.

Distribution.—Paleotropic and subtropic.

Geologic range.—Paleocene to Recent.

Remarks.—This world-wide genus is characterized by its turreted shell with a long spire consisting of many whorls. The shell is sculptured with more or less strong spiral grooves and axial ribs and generally shows great variability within each species.

Regarding the taxonomy of melanians there are different opinions: Morrison (1954) regarded it as a genus of the family Thiaridae Gray and Brandt (1974) also treated it as a genus of the subfamily Thiarinae Gray; Subba Rao (1989), following Pace (1973), regarded *Melanoides* as a subgenus of genus *Thiara* Röding, of the subfamily Thiarinae Gray.

Melanoides cf. ***tuberculata*** (Müller, 1774)

Figures 5-11—16

Materials.—TMNH02124, TMNH02125, TMNH02126, TMNH02127, TMNH2128.

Description.—Shell small to medium in size for the genus, 20 to 24 mm long, dextral, moderately thin, elongate and turreted with eight remaining whorls. Spire elevated, long, apical angle about 21° to 25°. The early whorls including the apex eroded. Whorls increasing in diameter slowly and regularly, sides gently rounded in profile. Body whorl not very large and below the periphery only marked by spiral ridges. Suture shallow but distinct. Strongly sculptured with four to five spiral ridges crossed by closely spaced obtuse ribs. The ribs stronger than the spiral ridges in the early whorls, in later whorls it is formed into rows of tubercles. Aperture not well preserved.

Measurements (*in mm*).—

TMNH coll. cat no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02124	24.0+	10.5	13.0+	7.0+	—
02125	17.0+	9.0+	6.0+	—	—
02126	19.0+	11.0+	—	—	—
02127	18.0+	9.0+	—	—	—
02128	15.0+	5.0+	5.0+	—	25°
02129	25.0+	8.0+	—	—	25°

Stratigraphic range.—Upper member of the Arung Khola Formation to middle member of the Binai Khola Formation.

Fossil Localities.—F-65, F-12, F-17, F-18, F-19, F-13, F-21.

Remarks.—The present specimens are quite similar to the Recent species of *Melanoides tuberculata* (Müller). The fossil specimens have more prominent surface sculpture. However, the variability within the species is extremely great as pointed out by many authors (Van Benthem Jutting, 1956 ; Starmuhlner, 1974 ; Brandt, 1974). Therefore, we concluded that the fossil specimens belong to this species.

Genus ***Brotia*** H. Adams, 1866

Type species.—*Melania pagodula* Gould. Recent : Asia.

Distribution.—Southeast Asia.

Geologic range.—Pliocene to Recent.

Remarks.—The genus *Brotia* H. Adams is characterized by a long turreted shell, the spire being longer than the body whorl, which is smooth or sculptured with spiral ridges and/or axial ribs and may be ornamented with tubercles or spines.

The genus was established with *Melania pagodula* Gould as the type species and subdivided into several subgenera (Preston, 1915 ; Brandt, 1974 ; Subba Rao, 1989) with Morrison (1954) treating the subgenus *Antimelania* Crosse and Fischer as a genus. The Indian subcontinent species are all grouped under the subgenus *Antimelania* Crosse and Fischer by Subba Rao (1989) with a regularly rounded aperture at the base as a characteristic feature. Brandt (1974) similarly subdivided the genus into two subgenera *Brotia* s.s. and *Senckenbergia* Yen, for Thai species, the former with protracted peristome at the base and in the latter not protracted. The same criteria is applied in an opposite manner for other species, for example, *Melania variabilis* Benson, which is the type species of the subgenus *Antimelania* Crosse and Fischer, is regarded as a synonym of *Brotia costula* (Rafinesque) which is placed into subgenus *Brotia* s.s. by Brandt (1974) but has a rounded aperture base. Hence, the use of the criteria for further subdivision is rather confusing. Furthermore, in the case of the present fossil specimens the base of the aperture is generally not preserved. Therefore, we are reluctant to divide the genus into subgenera for the present fossil species based on the above character.

Brotia palaeocostula sp. nov.

Figures 5-17—23

Materials.—TMNH02130, TMNH02131, TMNH02132, TMNH02133, TMNH02134, TMNH02135, TMNH02136, TMNH02137.

Diagnosis.—Suture banded, beltlike, shell marked with spiral and axial ridges, in the latter whorls with relatively widely spaced prominent axial ridges with blunt spines just above the periphery.

Description.—Shell medium in size for the genus, 30 to 50 mm long, dextral, turreted, narrowly conic and a little thick. Spire high and elongated with gradually increasing whorls. Apex and early whorls eroded. Shell generally with two to five remaining whorls. Body whorl rounded, shorter than the spire. Suture between the whorls distinct, not impressed but banded beltlike appearance due to a parallel groove below it. Surface of the shell distinctly marked with spiral and axial ridges. Surface of the early whorls cancellate. In the last two whorls axial ridges more prominent with blunt projecting spines just above the periphery, strongly developed in the last whorl. The spines more pronounced in larger matured specimens. Below the periphery of the body whorl the area is marked with spiral ridges only. Aperture incompletely preserved, probably elongated oval in outline with thin outer lip.

Type.—Holotype : Figures 4-17, TMNH02130. Paratypes : Figures 4-18-23, TMNH02131, TMNH02132, TMNH02133, TMNH02134, TMNH02135, TMNH02136.

Measurements (*in mm*).—

TMNH coll. cat. no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02130 (Holotype)	50.0+	23.4	26.0+	—	35°
02131 (Paratype-1)	36.0+	23.0+	18.0+	—	—
02132 (Paratype-2)	36.5+	15.4+	—	—	—
02133 (Paratype-3)	33.0+	30.0+	18.0+	—	—
02134	36.0+	16.0+	18.0+	—	—
02135	28.0+	24.0+	22.0+	—	—
02136	25.0+	20.0+	18.0+	—	—
02137	26.0+	18.0+	13.0+	—	—

Etymology.—The present fossil species shows some similarity to the Recent species *B. costula* (Rafinesque), hence the name 'old-costula'.

Type Locality.—At the right bank of the Jhumsakhola river

about 600 m east of the confluence with the Tinaukhola river (F-72 in Figure 1). Middle member of the Binai Khola Formation.

Stratigraphic Range.—Upper member of the Arung Khola Formation to middle member of the Binai Khola Formation.

Fossil Localities.—F-65, F-72, F-17, F-20, F-18, F-16, F-13.

Remarks.—The species belonging to this genus are represented by many subgenera in Southeast Asia. The presently described species *Brotia palaeocostula* is most similar to *Brotia (Antimelania) costula* (Rafinesque) in shape but differs in surface sculpture, suture and size. The present species was collected from many localities and surface sculpture is consistent. Generally in large and mature specimens of the new fossil species, the sculpture is more pronounced. Due to its distinct surface sculpture and size we regard it as a new, extinct species.

Brotia sp. indet. **A**

Figures 6-1—3

Materials.—TMNH02138, TMNH2139, TMNH2140.

Description.—Shell medium in size for the genus, 30 to 40 mm long, dextral, turreted with elongated conic spire, moderately thick. Spire conical, high, nearly half the shell length. Apex and early whorls eroded. The shell consists of more than nine evenly increasing whorls. Early whorls nearly flat in outline but the later ones obtusely convex. Apical angle about 30° to 32°. Sutures shallow with area below it a flat and bandlike. Shell surface sculptured with prominent rounded axial ridges with three to four weak spiral threads. Axial ridges comparatively strongly developed, rounded, curved, and constricted at the narrow suture area. Body whorl larger, rounded, marked with eight to nine axial ribs; subequal with spire; and below the periphery marked with many prominent spiral ridges. Aperture is not well preserved.

Measurements (*in mm*).—

TMNH coll. cat. no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02138	37.0+	16.6	17.3+	–	32°
02139	30.6+	13.1	15.2+	–	30°
02140	39.0+	18.8	–	–	32°

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Localities.—F-19, F-8806, F8812.

Remarks.—There are only three slightly well preserved specimens and five poorly preserved ones. Although the shell surface as well as shape can be clearly seen, due to the lack of complete specimens characters such as the aperture cannot be observed. This species differs from *Brotia palaeocostula* in shell surface sculptures and size; the former has well developed axial ridges with weak spiral ridge and is smaller in size. It shows some similarity to fossil *Melania pseudepiscopalis* Blanford, 1883, but the present species has more closely placed axial ribs and is smaller in size. It is also somewhat similar in shell sculpture to *Thiara (Melanoides, 1876) herculea* (Hanley and Theobald, 1876) which is considered to be a synonym of *Brotia (Brotia) costula costula* by Brandt (1974). However, the present species is much smaller in size with weakly developed spiral threads and prominent axial ribs which do not develop spines. *Brotia* sp. B has more widely placed axial ridges with absence of spiral sculpture and *Brotia* sp. C has both spiral and axial sculpture more well developed than in *Brotia* sp. A. Due to lack of more well preserved specimens further identification is difficult.

Brotia sp. indet. **B**

Figures 6-4—7

Materials.—TMNH02141, TMNH02142, TMNH02143, TMNH02144.

Description.—Shell moderately large for the genus, 30 to 60 mm long, dextral, slender, elongated conic in shape, moderately thin. Spire long, more than two-thirds of the shell length, consisting of only six remaining whorls. Apex and early whorls eroded. Side of whorls obtusely rounded, slowly increasing in diameter. Suture impressed. In the early whorls shell surface sculptured with comparatively closely placed prominent axial ridges, slightly enlarged around the peripheral area. In the later whorls axial ridges more widely spaced and in the last two whorls ridges produced into short blunt tubercles. Axial ridges do not extend beyond the suture. Spiral sculpture absent. Body whorl a little larger and moderately rounded. Aperture not preserved.

Measurements (*in mm*).—

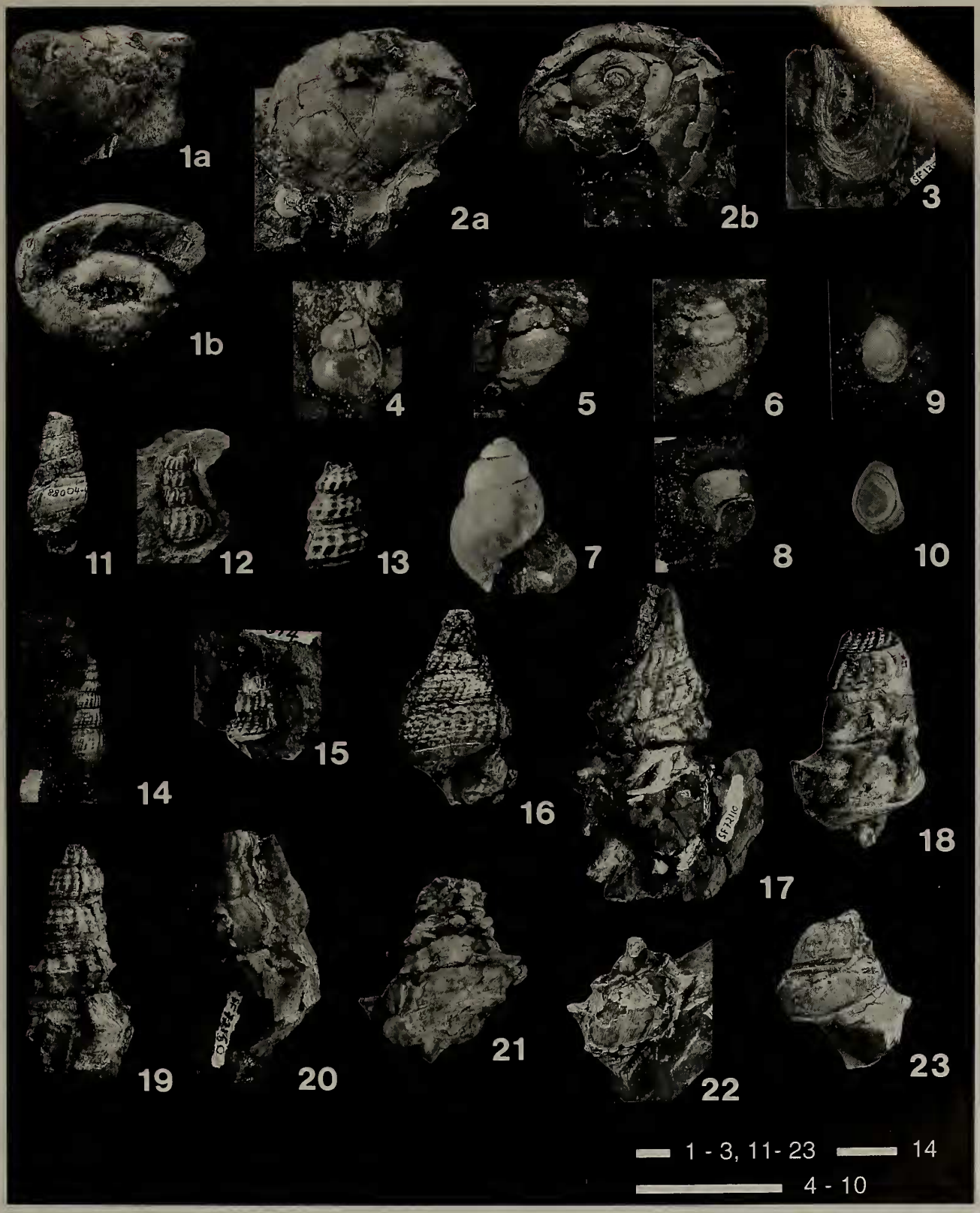
TMNH coll. cat no.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02141	56.5+	21.2+	25.0+	–	32°
02142	33.2+	9.5+	11.0+	–	–
02143	20.0+	8.0+	8.0+	–	–
02144	23.8+	10.2+	13.2+	–	–

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Localities.—F-13, F-8806, F-8812.

Remarks.—Although the shape and the sculpture of the poorly preserved sample clearly indicate its relation to the genus *Brotia*, further identification is difficult. There are only three specimens so far, one each from localities F-8806, F-

Figure 5. **1-3.** *Pila* sp. indet., 1: TMNH 02112, 2: TMNH 02111, 3: Operculum, TMNH 02113. **4-10.** *Bithynia* sp. indet., 4: TMNH 02114, 5: TMNH 02117, 6: TMNH 02118, 7: TMNH 02116, 8: TMNH 02121, 9: TMNH 02122, 10: TMNH 02123. **11-16.** *Melanoides* cf. *tuberculata*, 11: TMNH 02124, 12: TMNH 02125, 13: TMNH 02126, 14: TMNH 02128, 15: TMNH 02127, 16: TMNH 02128. **17-23.** *Brotia palaeocostula* sp. nov., 17: holotype, TMNH 02130, 18: paratype 1, TMNH 02131, 19: paratype 2, TMNH 02132, 20: TMNH 02134, 21: paratype 3, TMNH 02133, 22: TMNH 02135, 23: TMNH 02136. All scale bars: 5 mm.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88012 and F-13. The present specimens differ from *Brotia palaeocostula, Brotia* sp. A, and *Brotia* sp. C in having simple surface sculpture consisting of comparatively widely spaced axial ribs with absence of spiral sculpture.

Brotia sp. indet. **C**

Figures 6-8—11

Materials.—TMNH02145, TMNH02146, TMNH02147, TMNH02148.

Description.—Shell small in size for the genus, 20 to 35 mm long, dextral, slender, narrowly conic in shape, moderately thin. Spire high, long, more than half the shell length, consisting of six remaining convex whorls. Apex and early whorls eroded. Whorls slowly increasing in diameter with obtusely rounded sides, later ones less rounded and angled due to more developed subsutural and subperipheral spiral ridges. Body whorl large, rounded with nearly straight flat side between upper and lower spiral sculpture. Suture distinct but shallow. Shell surface marked by four to five thin spiral threads crossing the stronger axial ridges, giving a beaded appearance to the axial ridges. The axial rib does not extend beyond the suture. Basal part of the body whorl with spiral ridges only. Aperture not observed.

Measurements (in mm).—

TMNH coll. no. cat.	Height	Width	Height of body whorl	Height of aperture	Apical angle
02145	31.8+	11.2+	18.6+	—	50°
02146	20.7+	8.0	8.2	—	50°
02147	31.8+	13.5+	12.4+	—	50°
02148	28.7+	12.0+	10.4+	—	—

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Localities.—F-25, F-8806, F-17.

Remarks.—The specimens of this species are also few and poorly preserved. However, in shell sculpture it is quite different from the previously described three forms. Although the present fossil species is small in size for the genus, its characteristic turreted shell with distinct axial and spiral sculpture shows its affinity to *Brotia,* H. Adams rather than *Melanoides* Olivier. It shows some similarity in surface sculpture to the Recent species *Brotia (B.) pseudoasparata* Brandt, 1968, distributed in Southeast Asia ; but the former is much smaller in size and has a greater number of spiral ridges. Further identification is difficult until better preserved samples are found.

Subclass Pulmonata
Order Basommatophora Keferstein, 1864
Family Lymnaeidae Gray, 1842
Genus ***Lymnaea*** Lamarck, 1799

Type species.—*Limnaea stagnalis* (Linné)=*Helix stagnalis* Linné, 1758. Recent : Europe and Asia.

Distribution.—Worldwide.

Geologic range.—Palaeocene to Recent.

Lymnaea sp. indet.

Figures 6-12—13

Materials.—TMNH02149, TMNH02150.

Description.—Shell medium for the genus, dextral, elongate ovate in outline, rather thin. Spire small, acuminated, nearly equal in height with the width of the suture at the base of the spire. Body whorl much longer and larger than the spire, outer lip expanded and convex. Surface of the body whorl marked with fine growth lines. Aperture, columella and spire whorls not observed.

Measurements (in mm).—

TMNH coll. cat. no.	Height	Width	Height of body whorl	Apical angle
02149	11.4+	7.0+	9.4+	—
02150	3.2+	2.3	2.8	—

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Localities.—F-13, F-17.

Remarks.—So far only two specimens, incompletely preserved, have been collected from localities F-13 and F-17 (Figure 2). The shell is not completely preserved, but shell form is most like that of *Lymnaea* Lamarck. From its much larger body whorl, in comparison to the spire, and slightly expanded outer lip, the specimen from F-17 is distinguished as *Lymnaea* Lamarck. However, the second specimen from F-13 is of small size for the genus. Further identification can be done only if better preserved specimens can be collected. The rare occurrence of this species in the fossil assemblage is most probably due to the fragile nature of the shell of this group. Bhatia (1974) reported two species of *Lymnaea* from the Pleistocene of Upper Karewa, Kashmir, *L. (Galba) andersoniana* forma *similans* (Preston) and *L. (Pseudosuccinea) acuminata* (Lamarck) forma *hians* (Sowerby).

Family Planorbidae Gray, 1840
Genus ***Indoplanorbis*** Annandale and Prashad, 1921

Type species.—*Planorbis exustus* Deshayes. Recent : Malabar Coast.

Distribution.—South and Southeast Asia.

Geologic range.—Pliocene to Recent.

Remarks.—The genus *Indoplanorbis* Annandale and Prashad, differs from genus *Bulinus* Müller, in having a discoid shell and in certain minor anatomical characters (Hubendick, 1955).

Indoplanorbis cf. ***exustus*** (Deshayes, 1834)

Figures 6-14—15

Materials.—TMNH02151, TMNH02152.

Description.—Shell large in size for the family, discoidal and moderately thick. Upper and lower sides somewhat concave. The specimen consists of three to four whorls, rapidly increasing in size and rounded. All the whorls not

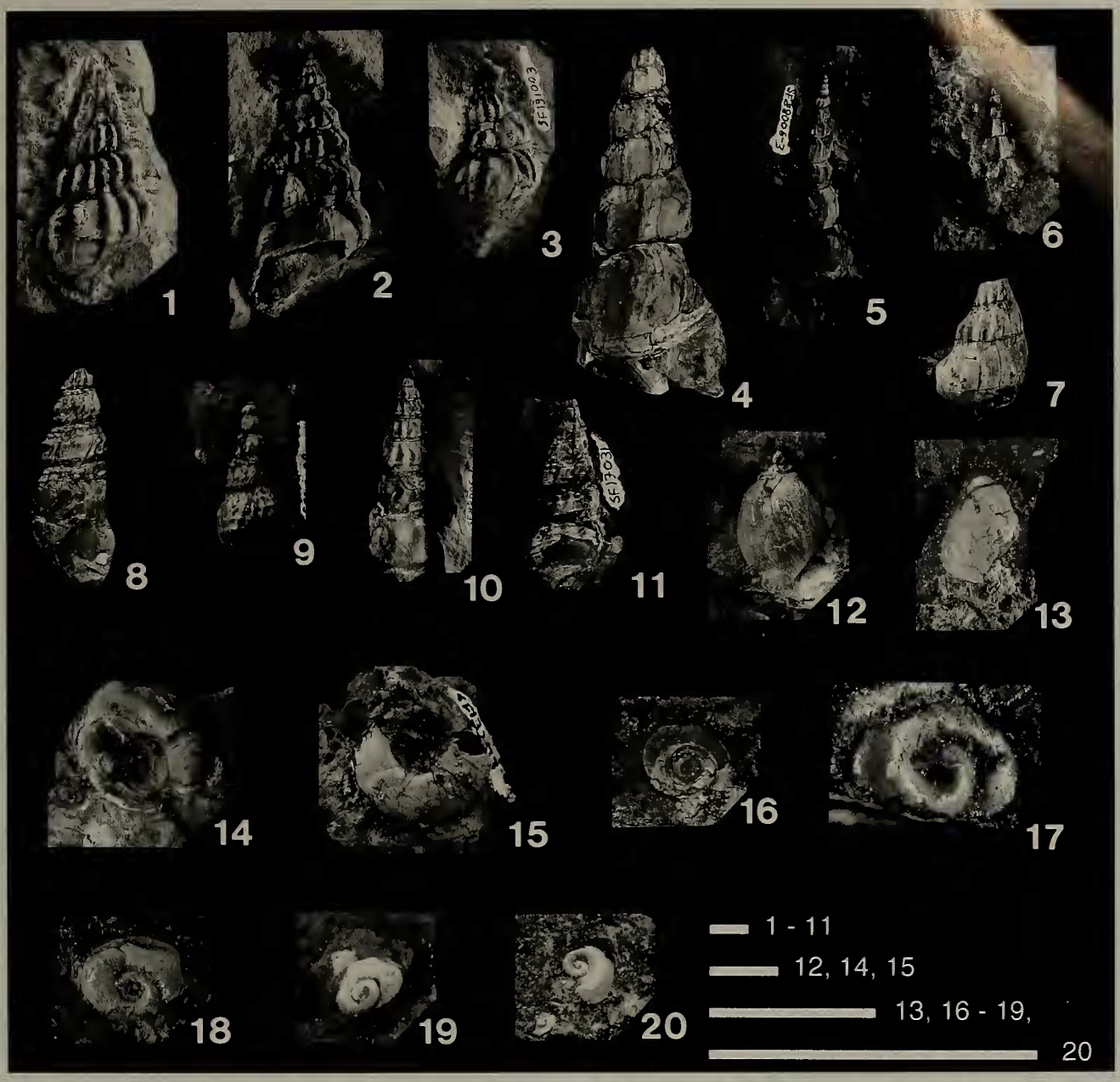

Figure 6. **1-3.** *Brotia* sp. indet. A, 1 : TMNH 02138, 2 : TMNH 02139, 3 : TMNH 02140. **4-7.** *Brotia* sp. indet. B, 4 : TMNH 02141, 5 : TMNH 02142, 6 : TMNH 02143, 7 : TMNH 02144. **8-11.** *Brotia* sp. indet. C, 8 : TMNH 02145, 9 : TMNH 02146, 10 : TMNH 02147, 11 : TMNH 02148. **12, 13.** *Lymnaea* sp. indet., 12 : TMNH 02149, 13 : TMNH 02150. **14, 15.** *Indoplanorbis* cf. *exustus*, 14 : TMNH 02151, 15 : TMNH 02152. **16-20.** *Gyraulus* sp. indet., 16 : TMNH 02154, 17 : TMNH 02155, 18 : TMNH 02153, 19 : TMNH 02156, 20 : TMNH 02157. All scale bars : 5 mm.

visible from basal side. Suture distinctly impressed. Surface of the shell marked with irregular but distinct growth striation. Aperture not preserved.

Measurements (*in mm*).—

TMNH col. cat. no.	Height	Diameter	Height of aperture
02151	6.0+	10.9+	–
02152	4.0+	10.0+	–

Stratigraphic range.—Middle member of the Binai Khola

Formation.

Fossil Locality.—F-13.

Remarks.—Large number of incomplete and broken specimens are collected from locality F-13, only two are more completely preserved. The aperture is not preserved and the shell is slightly compressed with only one side visible. The present specimen is most similar to the Recent widely distributed *Indoplanorbis exustus* (Deshayes) in shape, size and surface sculpture. Bhatia (1974) reported *I. exustus* from the Pleistocene Upper Karewa, Kashmir, India, his specimens are much larger than the presently reported specimens which may be immature shells.

Genus ***Gyraulus*** Charpentier, 1837

Type species.—*Planorbis albus* Müller=*Planorbis hispidus* Draparnaud. Recent: Switzerland.

Distribution.—Europe, Asia, Africa and North America.

Geologic range.—Jurassic? to Recent.

Remarks.—The discoidal shell of this genus is small, less than 10 mm in diameter.

Gyraulus sp. indet.

Figures 6-16—20

Materials.—TMNH02153, TMNH02154, TMNH02155, TMNH02156, TMNH02157.

Description.—Shell very small in size, ranging from 2 to 4 mm in diameter, discoidal, dextral and thin. All the whorls visible from above but apical part cannot be observed. Whorls increasing in diameter rapidly and consist of two and a half to three whorls. Body whorl larger and a little expanded around the aperture.

Measurements (in mm).—

TMNH coll. cat. no.	Height	Diameter	Height of aperture
02153	–	2.5+	–
02154	–	4.0+	–
02155	–	2.5+	–
02156	–	1.5+	–
02157	–	0.8+	–

Stratigraphic range.—Middle member of the Binai Khola Formation.

Fossil Localities.—F-13, F-72, F-21.

Remarks.—The shells of this species are abundant at few localities. Generally only one side of specimens can be observed, preventing accurate identification. These small, discoid and dextral shells are grouped into *Gyraulus* Charpentier. Due to the thin and fragile nature of the shell, preservation is poor, identification to species level is not possible at present. In the fossil state the genus is reported by Bhatia (1974) from the Pleistocene Upper Karewa, Kashmir.

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